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Absorption Spectroscopy of Si, Al, and Mg Tracers in a Multi-Layered CH Foil Heated By Z-Pinch Radiation

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Abstract

Sandia National Laboratories' Z machine provides a variable-width, high power x-ray pulse that can be applied to basic science experiments on the interaction of x-rays with matter. For this work, Si, Al, and Mg tracers of thickness ~9e17 atoms/cm^2 were embedded at different depths in 7.7 um and 11.5 um parylene (CH) foils. Time-integrated absorption spectra of these tracers provide information on the radiation profile in the foil leading up to the time of peak z-pinch power. This data is compared to computational models in two ways. First, the SPECTROFIT chi-squared fitting program is applied to determine the best-fit contours in temperature-density phase space between the data and JATBASE calculations of the atomic level transitions. Second, the experiments are simulated by BUCKY 1-D radiation-hydrodynamics calculations using a time- and frequency-dependent radiation boundary condition determined by VISRAD 3-D view factor simulations of the z-pinch diode region. The calculated plasma conditions are then post-processed by a collisional radiative equilibrium (CRE) model in the SPECT3D spectral analysis code to determine the relative amplitude of absorption features over the spectral range of interest. These calculations, and their comparison to the experimental data, will be presented and discussed.

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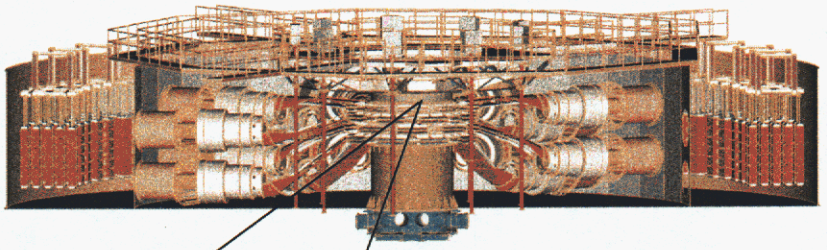
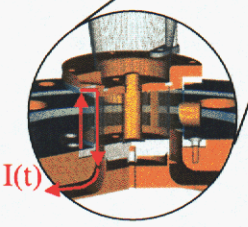
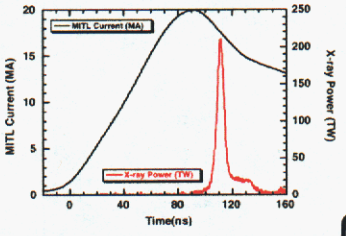
Sandia's Z machine provides a test-bed for basic science experiments on the interaction of x-rays with matter.





Z-pinch current/power profiles*



*R. B. Spielman et. al., Plasma Phys. Control. Fusion, **42**, p. B157 (2000).

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A 7.7 μm planar CH foil with Si, Al, and MgF_2 tracer layers was fielded on shot z873

Time-Integrated
Convex Crystal Spectrometer
(Si, Al and Mg K-α absorption spectra)

Foil Sample

1800 ÅSi

1500 ÅAl

3100 ÅMgF_2

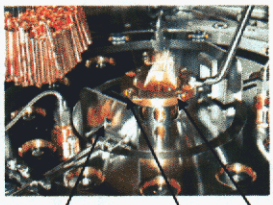
7.7 μm of CH @ 1.11g/cc

Time-Resolved X-ray
Pinhole Camera
(Pinch radius vs. time)

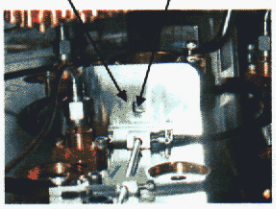
Z-pinch

XRDs and Bolometers
(Pinch power vs. time)

Current-Return
Can



Aperture Foil Current-Return Can



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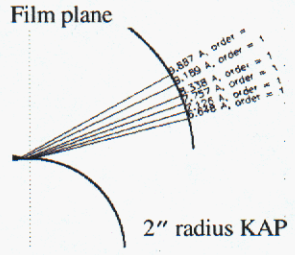
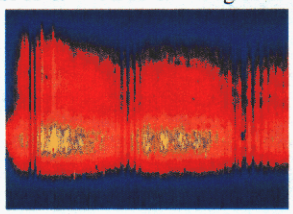
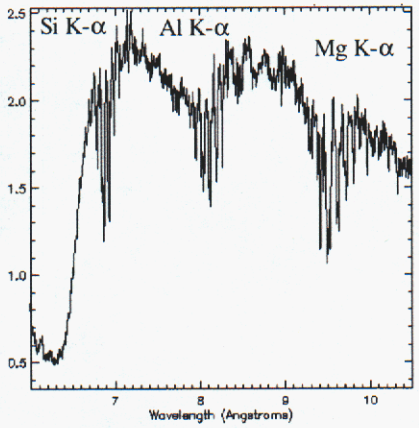
A time-integrated convex crystal spectrometer measured Si, Al and Mg K-α transitions in absorption.







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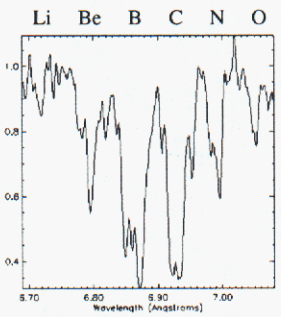
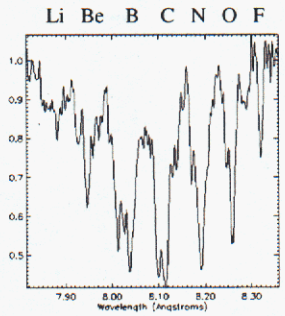
Each absorption spectra shows charge states up to Li-like

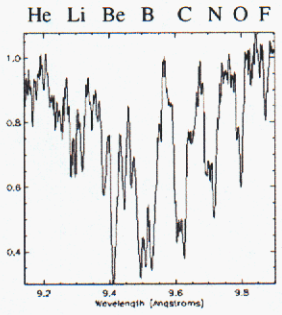
Si



Al



Mg



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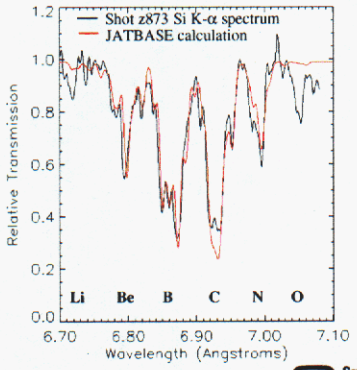
The time-integrated data can be compared to single-point atomic/plasma physics calculations through an automatic chi-squared fitting program called SPECTROFIT.

SPECTROFIT

- Reads detailed line-opacity tables generated by the JATBASE code
  - LTE and Non-LTE opacities
  - Arbitrary plasma mixtures
- Compares two relative transmission absorption spectra (i.e. experiment vs. calculation) at discrete temperatures and densities.
- Computes chi-squared fit parameter for a user-defined grid resolution over a specified temperature and density range.
- Reports fit-variance, χ^2, and $+1\sigma$

Comparison between time-integrated Si K-α data and a JATBASE calculation at T=40 eV and n_i=1.5x10^{19} cm^{-3}



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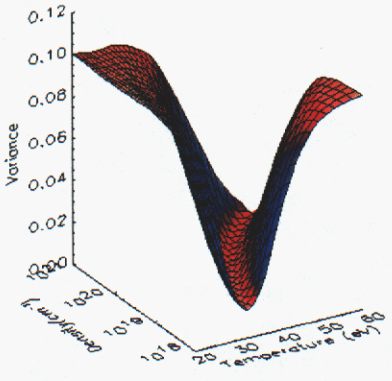
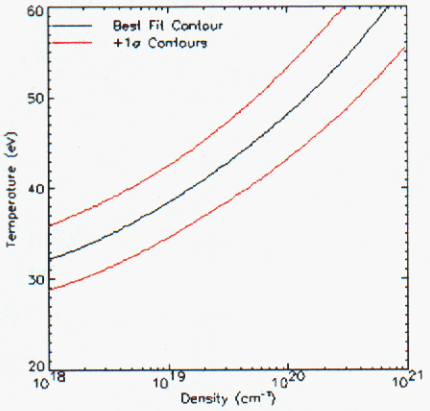
The SPECTROFIT χ^2 and fit-variance curves show the contour in temperature-density phase space where the calculated spectra best match the data.

Fit variance over the searched T-ρ phase space



Silicon K-α Fits



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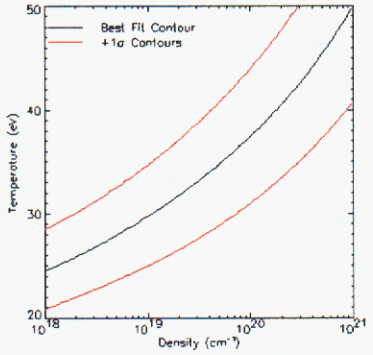
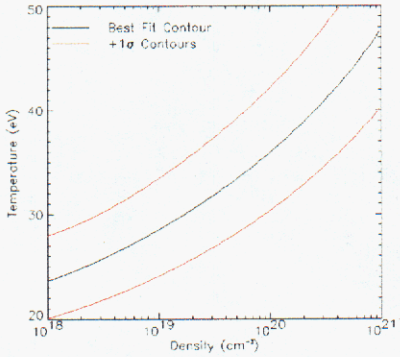
A similar analysis can be conducted on the Al and Mg K-α spectra, but gradients (in temperature, density, and/or time) make large error-bars.

Aluminum K-α Fits



Magnesium K-α Fits



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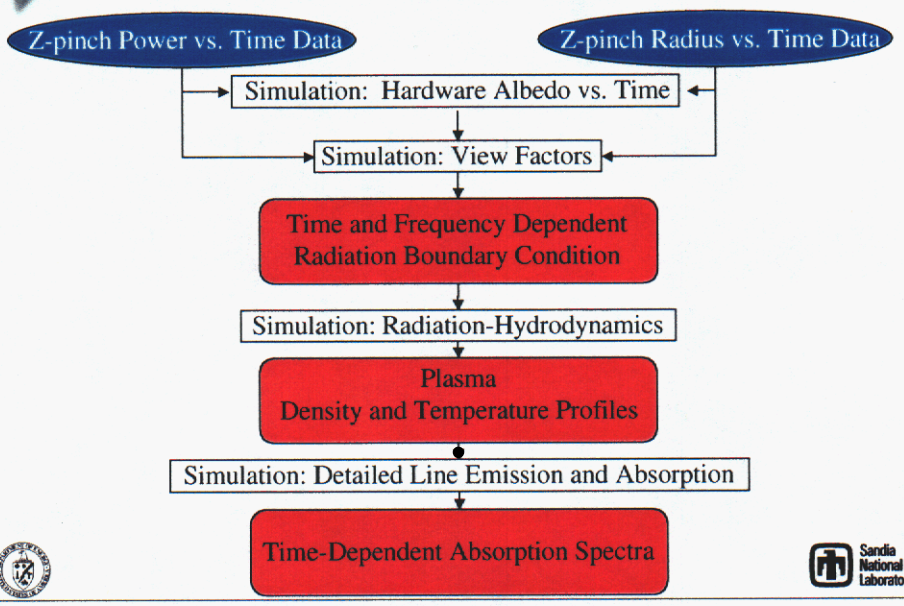
The plasma conditions in the sample can be calculated by coupling together a number of simulations



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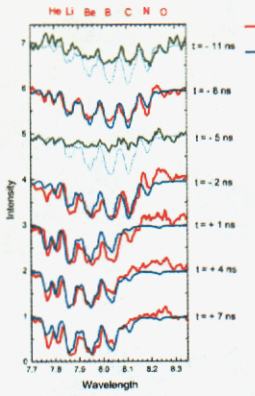
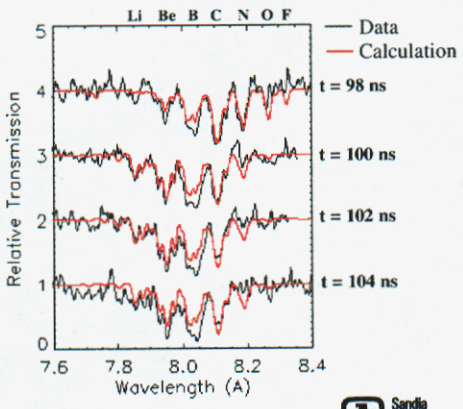
This method has worked well in simulating the charge states of Al layers tamped by thin (< 1.25 μm) CH layers on shots z419 and z597.

Calculated vs. Measured Aluminum K-α Spectra

z419



z597



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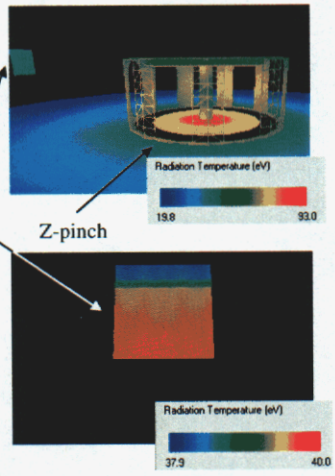
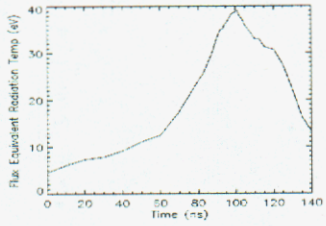
For shot z873, VISRAD simulations calculate a wide (20 ns fwhm), low-temperature (< 40 eV) x-ray radiation drive.

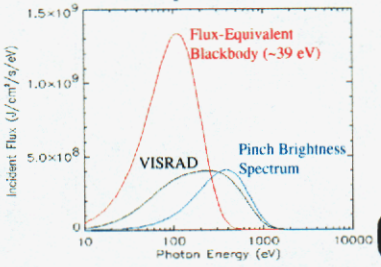
View-factor results at peak power



Calculated X-ray Drive



Incident Spectra at t = 100 ns



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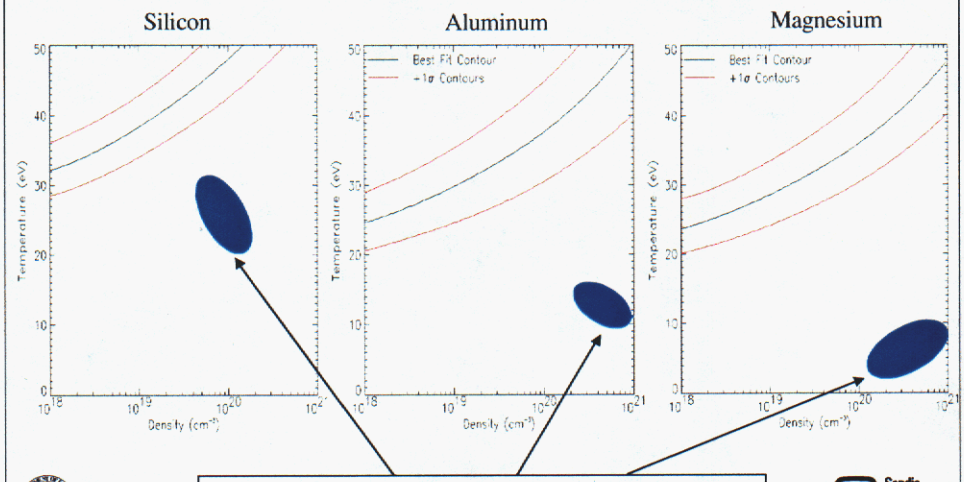
Unlike shots z417 and z597, BUCKY rad-hydro calculations of the thicker CH sample on shot z873 severely under-predict the charge-states in each tracer layer.



BUCKY calculated phase-space for peak radiation drive ±10 ns

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Based on the SPECTROFIT analysis of each tracer, it is concluded that the rad-hydro calculations under-predict the temperature, and over-predict the density throughout the sample.

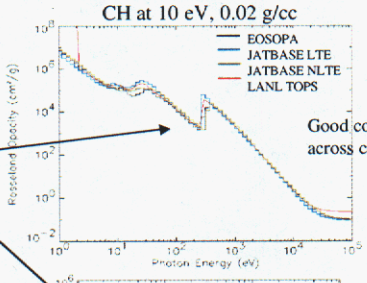
Possible Causes

Analytical

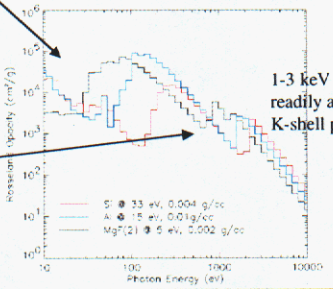
- Incorrect Opacities
  - CH opacity too high
  - Si, Al, and/or Mg opacity too low
- EOS models are too stiff

Experimental

- If there is separation in various CH layers, tracers can expand into gaps.
- Systematic error in measurement of CH layer thickness.
- Strong high-energy (non-thermal) component to the pinch spectrum.



Good comparison across codes



1-3 keV photons would be readily absorbed by K-shell photo-ionization

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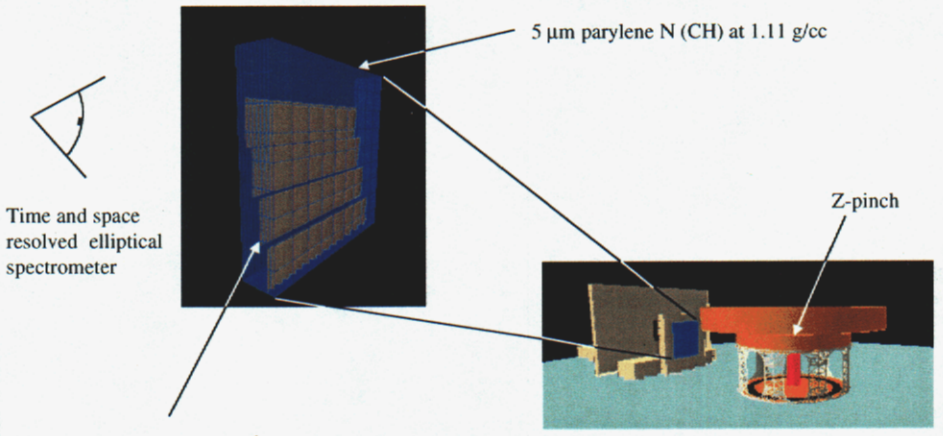
A new experiment is being fielded to address these issues in a more consistent way



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Summary

- Silicon, aluminum, and magnesium K-α absorption lines were measured on shot z873 at different depths within a 7.7 μm CH foil. This has placed an extra constraint on simulations that were previously used to analyze experiments conducted in a similar geometry with single foil tracer layers.
- A chi-squared comparison between atomic/plasma spectral calculations and each absorption spectrum has been completed. This analysis suggests that the temperature profile is much higher, and flatter throughout the sample than calculated by radiation-hydrodynamics simulations.
- While these methods have worked well on other experiments, the lack of agreement between calculations and this data suggests a fundamental misunderstanding in either the physical properties of the sample, or in the spectral distribution of the z-pinch radiation.
- An integrated experiment has been designed to simplify the basic conditions, and further address these issues.

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